# A Case study of teachers' pedagogical content knowledge in the implementation of integrated STEM education

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## Abstract

Integrated approach in learning STEM education promotes critical thinking, collaboration and creativity and have the advantage in making STEM subjects more relevant, increasing the motivation in learning and improving students' achievement and perseverance. The role of the teacher is crucial in integrating the STEM concepts and skills, instructions as well as managing the students. However, many educators may not be familiar with the teaching and learning of integrated STEM as an approach as most they were trained in one or two STEM disciplines. This paper presents a qualitative case study that evaluates the context of the implementation of integrated STEM education focusing on teachers' pedagogical content knowledge (PCK). This study reveals that there is a lack of PCK among the teachers in implementing integrated STEM education as an approach in teaching and learning. The findings of this study provide a starting point for a better understanding of the needs in integrated STEM education among the teachers here and guide the selection of intervention in the implementation of STEM education. Teachers' professional development programs and collaboration with STEM community of practice may facilitate teachers to acquire the STEM education PCK.

**Keyword:** STEM education, Pedagogical Content Knowledge, Case Study, Integrated STEM education

## Abstrak

*Kaedah pembelajaran pendidikan STEM bersepadu memupuk pemikiran kritis, kolaborasi dan kreativiti, serta mempunyai kelebihan menjadikan subjek-subjek STEM lebih releven, meningkatkan motivasi dalam pembelajaean serta meningkatkan pencapaian pelajar. Peranan guru adalah penting dalam menyatukan konsep dan kemahiran STEM, mengurus pengajaran dan pembelajaran pelajar. Namun, ramai pendidik mungkin tidak begitu biasa dengan pendidikan STEM bersepadu sebagai suatu kaedah pengajaran dan pembelajaran. Ini kerana ramai di antara mereka hanya menerima latihan dalam satu atau dua disiplin STEM. Artikel ini merupakan suatu kajian kes kualitatif yang menilai konteks pelaksanaan pendidikan STEM bersepadu yang berfokuskan pengetahuan konten pedagogi guru-guru. Kajian ini menunjukkan terdapat kekurangan pengetahuan pedagogical kandungan guru dalam pelakasanaan pendidikan STEM secara bersepadu dalam pengajaran dan pembelajaran. Hasil kajian ini memberikan titik permulaan untuk lebih memahami keperluan para pendidik dalam pendidikan STEM bersepadu dan membantu dalam pemilihan intervensi dalam pelaksanaan pendidikan STEM. Program pembangunan professional dan kolaborasi dengan komuniti STEM berkemungkinan dapat membantu guru-guru meningkatkan pengetahuan pedagogikal kandungan dalam pendidikan STEM bersepadu ini.*

***Kata Kunci:*** *Pendidikan STEM, Pendidikan STEM bersepadu, Pengetahuan pedagogical kandungan, kajian kes*

# INTRODUCTION

STEM education in Malaysia is either associated with teaching STEM related individual subjects, a learning package offering learning pathway for STEM elective subjects or as an integrated STEM approach (KPM, 2016). The description of STEM education as discrete STEM subjects and learning packages have a long standing in the previous and current curriculum. The definition of STEM education as an integrated approach that blends the STEM content, skills and values in solving contextual problem seems to agree with that in many of the literature (Jolly, 2017; Kelley & Knowles, 2016; Kim et al., 2015; Roberts, 2012; Truesdell, 2014; Xie, Fang, & Shauman, 2015). Integrated approach in learning STEM education promotes critical thinking, collaboration and creativity (Burrows, Lockwood, Borowczak, Janak, & Barber, 2018). It also have the advantage in making STEM subjects more relevant, thus increasing the motivation in learning and improving students' achievement and perseverance (Guzey & Moore, 2015; NRC & NAE, 2014) Moreover, many of the solutions to global challenges for instance, regarding environment, health, energy often involves combination of interdisciplinary concepts and skills (Shernoff, Sinha, Bressler, & Ginsburg, 2017).

However, many educators may not be familiar with the teaching and learning of STEM education as an approach. It requires the integration of knowledge, skill and value in STEM disciplines through strategies such as scientific inquiry and project-based learning to solve a contextual real-world problem. This is because most educators were trained in one or two STEM disciplines such as science and, or mathematics (NRC & NAE, 2014). Furthermore, most schools still have separate STEM subjects in all the classes (Shernoff et al., 2017). Integrated STEM education is meant to complement the discipline specific instruction and is not meant to replace them (Cambell, Coral & Jobling, 2014). Therefore, it may not be easy for teachers to make effective STEM connection as it requires them teach STEM content in deliberate ways in order for students to understand the application of STEM knowledge in contextual problems (NRC, 2011). They have to make explicit cross-cutting connections between the STEM subjects in planning and implementing their own STEM material so that students understand how STEM content is applied to authentic real- world context. Students and teachers may find it difficult and burdensome to link their compartmentalized knowledge and skills for each subject even though in the real-world situation many of these disciplines are interconnected. This is also reflected by Dickerson, Cantu, Hathcock, McConnell, and Levin (2016) in which they mention the similar struggles of many educators in the United States in integrating STEM education in their classroom teaching. Thus, it is crucial to understand the current challenges in the implementation of integrated STEM education as an approach to learning. This paper presents a qualitative case study that evaluates the context of the implementation of integrated STEM education focusing on teachers' PCK in STEM education. The findings of this study provide a starting point for better understanding of the needs in integrated STEM education among the teachers here. It also informs and guide the selection of intervention in the implementation of STEM education.

# LITERATURE REVIEW

## Pedagogical Content Knowledge (PCK)

Pedagogical content knowledge (PCK) is conceptualized by Shulman (1986) which generally refers to an integration of pedagogical knowledge and content knowledge. It involves the transformation of the subject's content into comprehensible forms presented to students. It is a shift from teachers' own understanding of the content for themselves into the ability of explaining them in ways that can be grasped by the learners. This includes various ways of representations, organization and adaptations in instructions to suit the diverse interest and abilities of the students that are essential for effective teaching ( Shulman, 1986, 1987). In fact, PCK is a special feature that is unique to the professionalism of teachers that distinguish them from other professionals such as scientists or engineers.

Content knowledge consists of syntactic knowledge and substantive knowledge of a subject. Substantive knowledge is the knowledge of the subject matter which includes concepts, theories and ideas which often developed over time through personal learning using established practices and approaches (Anderson & Clark, 2012; Ball, Thames, Phelps, & Ball, 2008; Koehler, Mishra, & Cain, 2013). Teachers' substantive knowledge is crucial as it enables students to receive the right information and thus preventing the development of misconception about the subject of a particular topic (Koehler et al., 2013). Another category of content knowledge is the syntactic knowledge which is the knowledge about the subject matter (Anderson & Clark, 2012). For example, knowledge about the nature of the subject, the means and principles by which the content of the subject develops and becomes accepted.

However, these knowledge needs to be organized and transformed in ways that can be easily grasped by the learners. This requires the pedagogical knowledge which involves various instructional processes and practices that deliver the content knowledge to the students (Shulman, 1987; Shulman, 1986). This includes understanding educational purpose, values and aims. It also encompasses the knowledge on how students learn and their characteristics, lesson planning and assessment and classroom management skills (Koehler et al., 2013).

Grossman (1990) described five inter-related components of PCK specifically in teaching science which are results of the blending of the components of content knowledge and pedagogical knowledge. First, is teachers' orientation to teaching science which are the basic beliefs and attitude towards the purpose and goals for science teaching. Secondly is the knowledge of students' understanding about a topic and areas which they may find difficult to comprehend. This also encompasses knowing the learners' motivation, learning style, ability, interest and developmental level. Both of these knowledges will guide the instructional decisions, the choice of instructional strategies, curricular material and assessment. Third is the knowledge of the science curriculum both horizontally and vertically as it helps teachers to understand the importance of a particular topic in relation to the other topics. It will enable teachers to identify essential concepts and modify activities in order students to have a necessary conceptual understanding. Fourth is the knowledge of instructional strategies in delivering the subject or topics. For example, inquiry-based learning, problem-based learning and project-based learning are some of the strategies in science teaching. Finally, is the knowledge about assessment which is about the knowledge of areas of science learning that need to be assessed and also knowledge of the relevant assessment methods in science.

**Figure 1** shows the summary of PCK in science learning that derived from the blending of content knowledge and pedagogical knowledge.

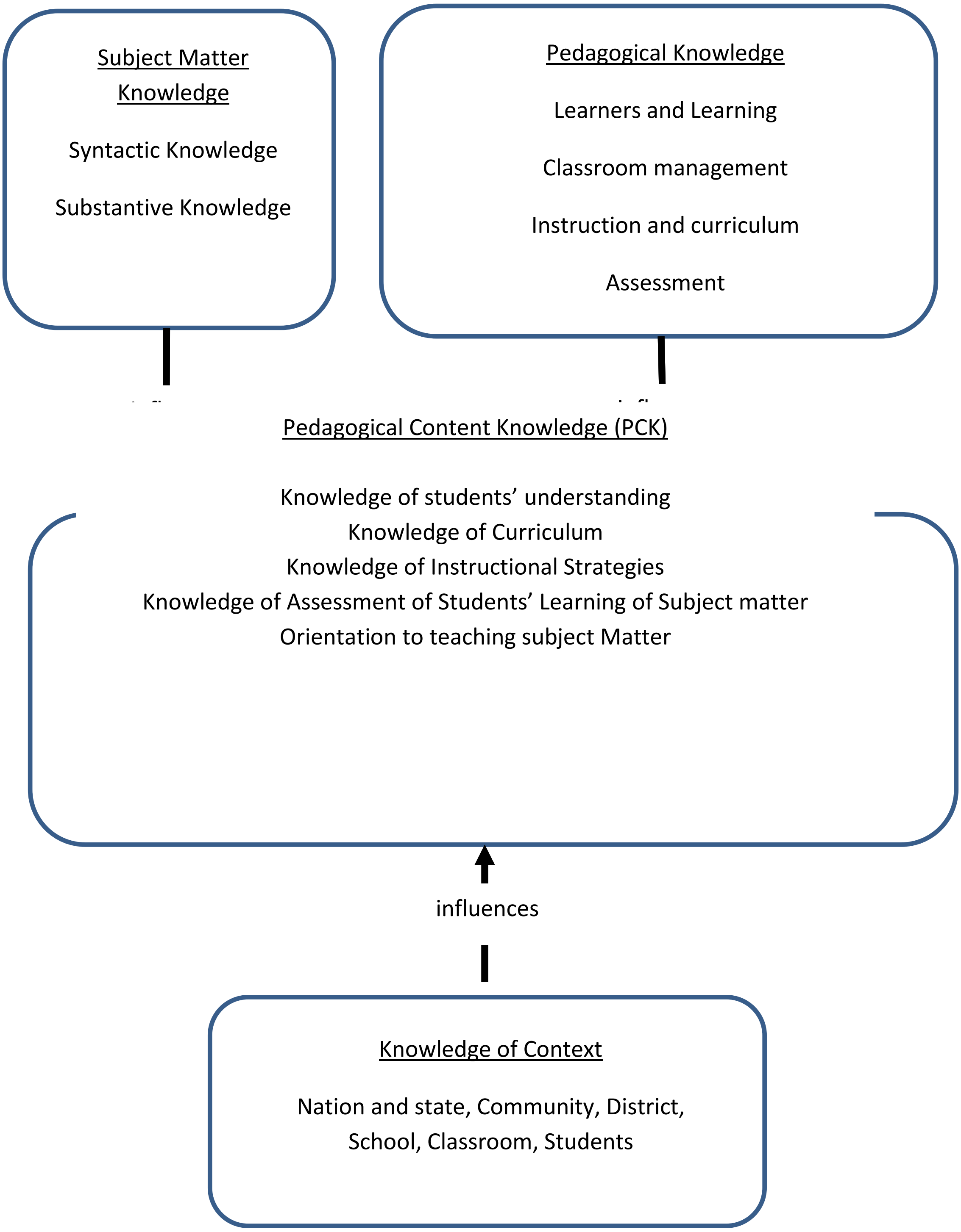


**Figure 1:** Summary of PCK by Grossman (1990)

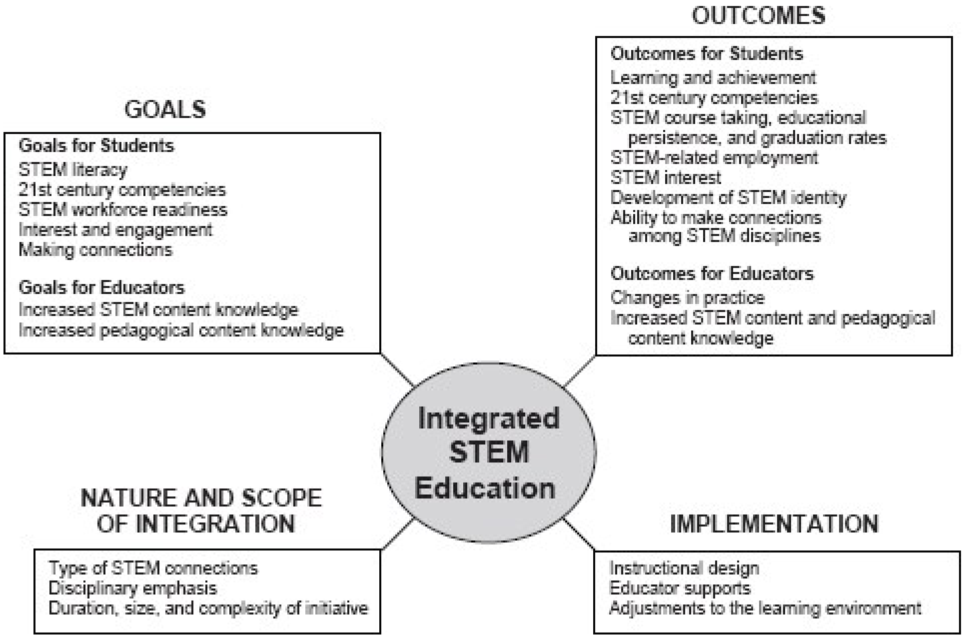


**Figure 2:** Descriptive Framework of Integrated STEM education

(NRC & NAE, 2014: page 32)

Figure 2 presents the descriptive framework of integrated STEM education proposed by the U.S. National Academy of Engineering and National Research Council, listed the goals, outcomes, implementation as well the nature and scope of integration (NRC & NAE, 2014) . One of the goals for integrated STEM education is to increase STEM PCK in order to see the change in teaching practice. It is important for teachers increase their PCK as this will facilitate to achieve the desired outcomes for teachers and students. In order for students to develop the right concepts, teachers need to be equipped with substantial knowledge about the topics involved. The solution of contextual problem is an important aspect of any integrated STEM education programme or activity. The problems are usually ill-defined and may involve different aspects of science, mathematics, engineering and/or technology in order to find the solution. Therefore, teachers' STEM subject content knowledge is important in order to guide students to apply the correct concepts and skills to solve the problem. Teachers must also have the right orientation in terms of their belief and attitude towards the goals and outcomes of integrated STEM education for the students. Without the proper understanding of the definition especially with regards to the nature and scope of integration, as well as the goals of integrated STEM education, teachers may end up in misconception or carrying out the STEM education as the usual individual STEM subject teaching and learning.

With regards to the students, educators need to know their motivation, learning style, ability, interest and developmental level as well as the STEM topics or areas that might be difficult for the students to grasp. All these will guide the choice of instructional strategies and approaches to deliver the lesson or to carry out the activities. Project-based learning (PjBL) seems to be the preferred instructional method for implementing integrated STEM education which model the twenty-first century classroom (Erdogan & Bozeman, 2015). Teachers need to how to conduct PjBL, especially in terms of managing and facilitating the students in such a way that allow them to effectively engage in projects with complex tasks. With regards to assessment in integrated STEM education, teachers need to know how to assess students' realistic products and solution to real world problems formatively and summatively. This requires a shift from the usual high stakes testing in schools or public examination.

## METHODS

This qualitative case study is exploratory in nature as there was lack of documented previous research on the teachers' challenges in integrating the concepts and skills between the STEM subjects. Purposive sampling strategy particularly maximum variation (heterogenous) sampling (Patton, 2002) was used in selecting the schools that aims at describing the central themes that cut across a small sample of great diversity. The selection of schools was based on the results of Form Five (Grade 11) standardized examination known as Malaysian Certificate of Education (*Sijil Pelajaran Malaysia*, SPM). The district's SPM 2016 schools' average grade (*Gred Purata Sekolah*, GPS) ranking which can be obtained from the district's education office was used to select the top, average and the lowest performing school.

In the selected schools, the head of science and mathematics department, head of science panel, head of mathematics panel were interviewed and lower secondary level Science, Mathematics, Design of Technology (*Rekabentuk Teknologi*, RBT) and Basic Computer Science (*Asas Sains Komputer*, ASK) teachers were selected. RBT teachers were selected as the content and skills in RBT subject are similar to engineering design process (EDP). Besides, the aspect of technology is included in the curriculum standard of RBT and ASK. Six focus group interviews were conducted. Four one-to-one interviews were conducted. The interviews were conducted in Malay language. Table 1 shows the list of participants in this study.

**Table 1:** List of participants

| Focus Group | Participants in School A | Participants in School B | Participants in School C |
|---|---|---|---|
| Focus group 1 (Administration) | - | 3<br>Head of RBT panel (RPB), Head of Science Panel (SPB), Head of Mathematics Panel (MPB) | 2<br>Head of Science and Mathematics Department (SMDC), Head of Technic and Vocational Department (TVDC) |
| Focus group 2 (Subject teachers) | 5<br>RBT teacher (RA), Science teacher 1(SA1), Science teacher 2 (SA2), Science teacher 3 (SA3), Science teacher 4 (SA4) Mathematics teacher 1(MA1), Mathematics teacher 2 (MA2) | 4<br>Science teacher (SB), Mathematics teacher 1 (MB1), Mathematics teacher 2 (MB2), RBT teacher (RB) | 8<br>Science teacher 1 (SC1), Science teacher 2 (SC2), Science teacher 3 (SC3), Mathematics teacher 1 (MC1), Mathematics teacher 2 (MC2), RBT teacher 1 (RC1), RBT teacher 2 (RC2), ASK teacher (AC) |
| One to one interview | 2<br>Science teacher 2 (SA2) Science teacher 4 (SA4) ASK teacher (AA) | 2<br>Head of Science and Mathematics Department (SMDB), ASK teacher (AB) Science teacher (SB) Mathematics teacher (MB1) | 0 |

Open-ended interviews were conducted to obtain rich and in-depth information regarding their experience of STEM education in their school. Semi-structured interview consisting of open-ended questions was used to guide the discussion as follows:

*Is there any integrated STEM education implemented here?*
*(a) If yes,*

*please describe the examples*
*Any challenges/ problems?*

*(b) If No.*

*Reasons*
*Integrating the subjects*
*Application in solving contextual problems*

Conversations were recorded using audio recorder which were later transcribed manually. Document analysis was also conducted to reveal the needs and the problems in the implementation of integrated STEM education in the lower secondary level. Apart from that, the education profile of the teachers was also obtained from the schools' database with permission.

The interview transcripts were read through to obtain a sense of the whole. It was then broken down or condensed into smaller meaning units containing the insights related to the research questions of this study. A code was given to label the units. The latent or the interpretative meaning of related codes was grouped into a theme. The coding process was carried out manually assigning codes to label meaningful condensed units which contain insights related to the research questions. A theme refers to a specific pattern found in data that one is interested which can be manifest content of the latent content of the data (Joffe & Yardley, 2004). The selection and formulation of the themes can be emerging from the raw data itself (inductive coding) or derived from the theoretical ideas that frame the study (deductive coding). In this study, the themes were derived from components PCK. In analysing the documents, this study involved the iterative process of scanning, reading and interpretation which combined the elements of content analysis and thematic analysis (Bowen, 2009). Content analysis was used to identify keywords related to STEM disciplines. Certain level of interpretation was applied in triangulating with the interview findings. For this writing, the interviews excerpts were translated from Malay language into English.

## FINDINGS

The interview excerpts revealed three themes related to PCK which are 'lack of STEM content knowledge', 'lack of STEM pedagogical knowledge' and 'lack of STEM orientation'. Appendix 2 presents the themes with its codes and the representative interview excerpts.

### Lack of STEM content knowledge

The codes under this theme are 'do not have the knowledge', 'I don't know' and 'do not have the qualification'. The RBT teachers in this study admitted the lack of content knowledge in delivering their subject. For example, RB was aware of the integrated elements of science and mathematics in the RBT subject. However, she admitted that she does not have the content knowledge of the science and mathematics to teach the content in RBT. She further lamented that she does not even have the content knowledge to teach her own subject of RBT when it was first introduced in 2017. This was also echoed by RBT teacher in school A, RA who admitted that she does not have the knowledge in science to integrate in RBT. In another example, RPB specifically described he does not have engineering qualification to teach students about construction. He implied that there is a need for STEM expertise to facilitate learning in the school.

From the participants' academic and professional education background, most of the teachers have undergraduate degree qualification that is related to the subject that they are teaching (**Error! Reference source not found.**). Table 2 shows the analysis of the academic qualification with the subjects taught by the research participants. 65% of the teachers have the qualification that matches with the subjects taught. All of the teachers teaching ASK has academic qualification that is related to computer science or information technology. However, none of the RBT teachers have academic qualification related to technology or engineering. One of the teachers in school A, SA1 has an academic qualification in Innovation and Design which is related to RBT, but she was not assigned to teach this subject. One of the most probable reasons may be due to the fact that RBT was a newly introduced subject in 2017. The schools may not be aware of the content and skills required in the subject. Many of the teachers do not have a qualification that directly related to the subject that composed of design, innovation, invention and technology in the schools. Hence, the three schools assigned teachers who had been teaching the subject Living Skills from the previous curriculum to teach RBT. Most of the science and mathematics teachers have matching academic qualification. Those who do not have the equivalent academic qualification, for example SA3, SA4 and MC1 were assigned to teach those subjects based on the schools' administration needs and decision. It was most probably due to lack of teachers of that particular subject or due to the experience of these teachers have in the subjects throughout the years of teaching.

**Table 2:** Analysis of participants' academic qualification with subjects taught

| Schools | Number of teacher with matching academic qualification (%) | Proportion of Science teachers with matching academic qualification (%) | Proportion of Mathematics Teachers with matching academic qualification (%) | Proportion of RBT teachers with matching academic qualification (%) | Proportion of ASK teachers with matching academic qualification (%) | Total Participants |
|---|---|---|---|---|---|---|
| A | 4<br>(57) | 3/5<br>(60) | 1/1<br>(100) | 0/1<br>(0) | - | 7 |
| B | 7<br>(78) | 2/2<br>(100) | 4/4<br>(100) | 0/2<br>(0) | 1/1<br>(100) | 9 |
| C | 6<br>(60) | 3/3<br>(100) | 2/3<br>(67) | 0/3<br>(0) | 1/1<br>(100) | 10 |
| Total | 17<br>(65) | 8/10<br>(80) | 7/8<br>(88) | 0/6<br>(0) | 2/2<br>(100) | 26 |

## Lack of STEM pedagogical knowledge

'Do not know how to apply STEM' and 'do not know how to integrate' are the closely related condes revealed under this theme. The science and mathematics teachers in this study seem to have the content knowledge for science and mathematics, but they do not know how to apply them and link with the RBT content. This is mainly because they do not know the content in RBT and do not have the pedagogical knowledge to connect and deliver in the integrated approach. Other teachers such as SC1 said that she does not know how to carry out integrated STEM education in class. Similarly, MB2 and SMDB said they are not sure how to integrate the subjects. The document Guideline in the Implementation of STEM in Teaching and Learning (*Panduan Pelaksanaan STEM dalam Pengajaran dan Pembelajaran STEM*) (KPM, 2016), provides a general guideline on STEM education teaching and learning process. It also provides examples of lesson plan for each STEM discipline. It emphasises of the general objectives for all school levels and characteristics of STEM teaching and learning classroom from pre-school to upper secondary level. However, teachers seem to lack motivation to read and go through the details in the document to learn and plan for STEM activities. When asked about the how the guideline helps in implementing STEM education, the Head of Science and Mathematics of school B, SMDB answered: "*If softcopy…Nobody wants to read…Lazy to read…Nobody cares about that…*"

**Lack of STEM orientation**

The code for this theme is ‘not sure about STEM education’. The findings on the interviews also reflect the lack of the right orientation in terms of their belief and attitude towards the goals of integrated STEM. Without the proper understanding of the definition and purpose of integrated STEM education, teachers may end up in misconception or carrying out the STEM education as the usual individual STEM subject teaching and learning. For example, TVDC said she does not know much about STEM education as she only have some basic information about it. Another instance is teacher AA, who was just transferred to school A and admitted that he just came to know about STEM education this year. However, he seems to relate STEM education with the existence of a STEM room in the school.

## DISCUSSION

Content knowledge, instructional strategies and teachers’ orientation to the subject matter are the components of PCK as described by Grossman (1990). This seem to be consistent with the literatures that state many teachers lack sufficient knowledge and skills to implement integrated STEM education in the classroom (Custer & Daugherty, 2009; Rockland et al., 2010). The lack of PCK may hinder the implementation and effectiveness of integrated STEM education among the students. Effective teachers who know how to integrate the available curriculum standards, develop and deliver the hands-on project-based instruction, are the backbone to the implementation of innovative STEM education (Yoder, Bodary, & Johnson, 2016).

Teachers’ undergraduate degrees are indications of their content knowledge in the subject that they are teaching. There are a few teachers in science and mathematics who are deficient in this measure. As for the RBT teachers, all of them do not have the undergraduate degree related to design process and technology which are main components of this subject. In fact Hill, Rowan and Ball (2005) mentioned that teachers’ knowledge in a particular subject is directly related with students’ learning and achievement. It is a crucial factor that determine whether integrated STEM education programmes or lessons can be carried out well either during formal classroom learning or after-school settings (NRC & NAE, 2014). Many educators may be unprepared with limited content knowledge in STEM subjects, lack of confidence and efficacy to carry out integrated STEM education programme (Nadelson et al., 2013). Content knowledge was found to correlate positively with teachers’ efficacy in teaching (Nadelson et al., 2013; Park & Oliver, 2008; Schoon & Boone, 1998). In a more detailed description, teachers’ efficacy in integrated STEM education is dependent on their subject matter knowledge and the ability to transfer the concepts and skills to the students through the choice of instructional strategies (NRC & NAE, 2014). When teachers have low efficacy in teaching any STEM concepts or skills, students are likely to develop misconceptions in the related concepts (Schoon & Boone, 1998). In short, teachers’ PCK in STEM education affects their efficacy in delivering any STEM education programme or lessons and this will affect the outcomes in students’ learning.

Educators also need to have pedagogical knowledge that facilitate the instructions of integrated STEM lessons or programme. In science education, the pedagogical knowledge includes orientation in the subject, instructional strategies, assessment, knowledge about the students and the current subject curriculum standards (Grossman, 1990). Orientation in a subject matter refers to teachers’ beliefs and attitude towards the goals of that subject. In the same way, orientation in integrated STEM education is about teachers’ basic beliefs and attitude towards the purpose and goals for STEM education. The proper understanding of the definition and purpose of STEM education will assist the teacher in planning effective lesson, activities or programs for the students. Knowledge about students will guide teachers to facilitate students in the mastering the essential concepts in the individual STEM discipline and at the same time making explicit connections between them (NRC & NAE, 2014). Teachers also need to know how to apply instructional strategies such as project-based learning (PjBL) in delivering STEM education program effectively. However, many teachers are not competent in carrying out PjBL in implementing integrated STEM education lessons or programs (Erdogan & Bozeman, 2015). They may not be familiar in managing students in such a way that allow them to effectively engage in projects with complex tasks. This may subsequently lead to negative attitudes towards PjBL. In terms of assessment, Erdogan and Bozeman (2015) mention that most of the STEM teachers are unable to perceive students' realistic products and solution to real world problems as a form of formative and summative assessment. They still relate assessment with the usual high stakes testing in schools or public examination.

Thus, a teacher's feeling of uncertainty about his or her abilities due to inadequate STEM subject matter knowledge and the knowledge about the appropriate instructional strategies; may be manifested in reduced confidence in teaching the related concepts. They are less likely to believe they can teach effectively and thus may lead to students' misconceptions. Park and Oliver (2008) viewed that teachers' increased efficacy will facilitate the enactment of their understanding in teaching through reorganisation of knowledge and selecting the most suitable instruction strategies to deliver to the students. Therefore, it is crucial for teachers to acquire the necessary PCK in integrated STEM education in terms of the content knowledge as well as pedagogical knowledge as these will increase the self-efficacy of teachers and ultimately promote effective learning among the students. Nevertheless, if teachers themselves have not experienced learning science, mathematics, engineering and technology in an integrated manner and applying the integrated concepts and skills to solve contextual problem, they are less likely able to deliver an effective or meaningful integrated STEM lesson or programme (NRC & NAE, 2014).

Teachers need mediation that facilitate and scaffold their PCK before they can mediate and deliver effective STEM education to the students. Professional development is one way to scaffold teacher's learning of STEM education as an approach. Besides, collaboration with STEM community of practice, engineers, scientists, agriculturists and universities lecturers in STEM field will also enhance the acquisition of STEM education PCK. Teacher professional development can support teachers in implementing changes, in this case STEM education, to achieve the desired students' learning outcomes. In-service teachers can increase their PCK specifically in integrated STEM through on-going professional development. Professional developments can be in the form of in-service courses or training. It can also be a collaboration or team learning through professional learning communities (PLC) that involved STEM expertise or STEM community of practice. Many studies had shown that on-going teachers development programme positively affect teachers' efficacy, confidence and motivation in teaching STEM education (Benuzzi, Golez, Grace, Hamm, & Straits, 2015; Bissaker, 2014; Nadelson et al., 2013; Slavit, Nelson, & Lesseig, 2016; Stohlmann, Moore, & Roehrig, 2012). A professional development program that extended over a period of time, for example one week or more, together with on-going support system and mentoring were found to be more effective (NRC & NAE, 2014). Kelley and Knowles (2016) suggested that teachers must be equipped with conceptual understanding of integrated STEM education approach. Teachers need to understand the nature of STEM education, its purpose and goals. They need to have the content knowledge as well as pedagogical knowledge in how to integrate the concepts and skills from the different STEM disciplines to guide students to solve real-world problems. Erdogan and Bozeman (2015) further describe that the professional development for STEM teachers have to focus pedagogical methods that aligned with authentic assessment for students in which their realistic products or solution to real-world problem is assessed formatively and summatively. In working with students, teachers need to know how to manage, guide and facilitate students' decision making and problem-solving through PjBL. Long term on-going professional development should also focus on exposing teachers to engineering principles and design in order to infuse them into the existing science classes (Rockland et al., 2010). This is because many teachers lack sufficient knowledge and skills in engineering to effectively carry out STEM education programs especially those related to design challenge (Custer & Daugherty, 2009). There is also a need for collaboration with other STEM expertise from universities or any higher learning institution or community of practice for extra and specific training in a particular STEM field. Daugherty (2008) mentioned that hands-on activities, teacher collaboration and instructor credibility are aspects that contribute to the effectiveness of integrated STEM professional development. Rockland et al. (2010) listed important factors for successful STEM education professional development which include: engaging teachers in practicing concrete tasks related to teaching, assessment, and observation of learning; drawing upon teachers' questions, inquiry and experiences; teachers' collaboration; building on teachers' current work with students; and providing modelling, coaching and problem solving in specific areas of practice.

However, the planning and implementation of effective professional development is an uphill task. Differences in teachers' diverse educational backgrounds, experiences and capabilities across the different STEM disciplines may pose difficulties in designing professional development programs that cater for the needs for all teachers (Custer & Daugherty, 2009). In cases where professional development aimed to facilitate collaboration between the STEM subject teachers, it is sometimes difficult to transfer the same level of collaboration into schools as teachers are surrounded by the existing time table, curricular and assessment requirements. It requires time and energy for teachers to learn new practices as it is often seen as an addition to the existing workload, bringing certain amount of anxiety. Thus, teachers might become resistant to change especially professional development that associate with the implementation of new curriculum reforms (Salami, Makela, & Miranda, 2015). Many may resort to short-term training or 'one-shot' approach. 'One-shot' staff developments often take place after school workshops or meeting unable to produce lasting changes in teachers' behaviour (Rockland et al., 2010). Therefore, carefully design of STEM education professional development need to take into consideration many factors to ensure its effectiveness to the teachers.

## CONCLUSION

The role of the teacher is crucial in integrating the STEM concepts and skills, instructions, managing the students. This study revealed the lack of integrated STEM education PCK among the teachers. This imply that the teachers require mediation acquiring substantial integrated STEM PCK in order to plan and execute effective STEM programme. Teachers' professional developments and collaboration with STEM expertise may facilitate teachers to acquire the STEM education PCK. STEM education professional developments either in the form of short-term courses or on-going professional learning community (PLC) equips teachers with STEM PCK that potentially change teachers' classroom practice and increase their efficacy in delivering effective STEM education programs or lessons. Similarly, collaboration with STEM community of practice may also improve teachers' STEM PCK as teachers are exposed to authentic application of integrated STEM concepts and skills in the real-world setting. For future research, more comprehensive integrated STEM professional developments programs that involved collaboration with STEM community of practice can be designed, either in the form of short-term courses or on-going PLCs for teachers. Impact studies can be carried out to determine the effectiveness of the various programs. It is hoped that all these will further facilitate the implementation of integrated STEM education.

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# Appendix 1

## Participants academic background

| Teacher | Academic/ professional education | Option subject | Teaching years | Currently teaching subjects |
|---|---|---|---|---|
| **School A** | | | | |
| RA | B.Ed | Domestic science | 10 | RBT |
| SA1 | B.Sc., Dip. Ed | Science<br>Innovation and Design (*Pengajian Rekacipta*) | 14 | Science |
| SA2 | B.Ed | Biology | 12 | Biology and Science |
| SA3 | Teaching Certificate, B.Ed | Economy<br>Geography | 21 | Science, Accounting, Additional Mathematics |
| SA4 | B.A., Dip. Ed | Commerce | 4 | Science |
| MA1 | B.Ed | Mathematics<br>Physics | 10 | Physics, Mathematics |
| MA2 | B.Ed | Mathematics | 22 | Mathematics |
| AA | Teaching Certificate<br>B.Ed | Interactive Multimedia<br>Visual Arts | 20 | Computer Science<br>Basic Computer Science (ASK)<br>Visual Arts |
| **School B** | | | | |
| SMDB | B.Ed | Special Education (Hearing Diabilities), Mathematics | 20 | Additional Mathematics |
| AB | B.Sc., Dip. Ed | Computer Science<br>Data Processing | 14 | ICT, Basic Science Computer (ASK) |
| SB | B.Ed | Chemistry<br>Biology | 8 | Science |
| MB1 | Teaching Diploma B.Ed | Mathematics | 24 | Mathematics |
| MB2 | B.Ed | Physics, Mathematics | 7 | Mathematics |
| MPB | B.Ed | Mathematics | 21 | Mathematics |
| SPB | B.Sc(Agriculture)<br>Dip.Ed | Science | 21 | Science |
| RB | Teaching Certificate<br>B.Ed | Malay Language | 20 | RBT, Malay Language |
| RPB | Teaching Certificate<br>B.A | Accounting<br>Science | 19 | RBT |
| **School C** | | | | |
| SC1 | B.Ed | Biology<br>Chemistry | 9 | Science |
| SC2 | B.Ed | Science | 11 | Science |
| SC3 | Teaching Diploma<br>B.Ed | Moral Education | 22 | Science |
| MC1 | Teaching Diploma<br>B.Ed | Malay Studies *(Pengajian Melayu)*<br>Social Science | 27 | Mathematics |
| MC2 | B.Ed | Mathematics<br>Physics | 10 | Mathematics |
| RC1 | Teaching Diploma<br>B.Ed | Malay Studies *(Pengajian Melayu)*<br>Local Studies | 22 | RBT |

| | | | | |
|---|---|---|---|---|
| | | (*Kajian Tempatan*) | | |
| RC2 | B.Ed | Business Management Commerce and Entrepeneurship | 2 | RBT |
| AC | B.Ed | Information Technology<br>Islamic Studies | 11 | ASK |
| TVDC | Teaching Diploma<br>B.Ed<br>M.Ed | Domestic Science | 24 | Vocational Subject (MPV) |
| SMDC | B.Ed | Statistics<br>Economy | 15 | Mathematics |

# Appendix 2

## Themes and codes from teachers' interview excerpts

| Themes | Codes | Teachers' interview excerpts |
|---|---|---|
| Lack of STEM content knowledge | Do not have the knowledge | "*Yes, in fertigation project (one topic in RBT), it has all the STEM element especially technology and engineering in agriculture field, but we do not have the knowledge to teach*" (RB)<br><br>"*RBT involved projects such as brief project, pictorial sketching, fertigation technology, fashion designs. We do not have the knowledge on how to teach the students, we do not have the skills…"* (RB) |
| | I don't know | "*As for me, I am teaching RBT, I do not know much about science, I only know some very basic science…*". (RA) |
| | Don't have qualification | *"….we want to teach engineering, but the teachers are language teachers, sound not logical. As for science and technology, they are still manageable, but not engineering. How can we teach the students? The buildings will collapse. We don't have the qualification. The school must have at least one teacher who is certified in this field so that we can teach the students in a proper way. Now, all we depend is on the internet as our reference." (RPB)* |
| Lack of STEM pedagogical knowledge | Do not know how to apply STEM | "*I am a science teacher and just started to teach this KSSM subjects this year. I still do not know how to apply STEM in my classroom teaching."* (SC1) |
| | Do not know how to integrate the subjects | "*For me I still do not know to integrate the subjects*". (MB2)<br><br>"*The problem is, this thing is still quite new. We still teach according to the previous, we just follow the DSKP. If regarding integration, we are still do not see it yet*." (SMDB)<br>"*The problem is that we have never seen their books (RBT) and they also never seen our books (science), and we find it hard to match, unless we go for training and relearn everything. Yes the problem is we haven't cross each others' content yet, so it is quite difficult to integrate*". (SA1) |
| Lack of STEM orientation | Not sure about STEM | "*If regarding STEM, I am not very sure. I only knew about it in this school, because there is no STEM in my previous school. Maybe because we don't have enough room. In this school we have a special room for STEM."* (AA)<br><br>"*We had briefing about STEM education, but it is not sufficient for us to implement it in classroom. We only know the surface and basic information."* (TVDC) |